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Pandey

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(54) **DETERMINING ACCESS POINT ORIENTATION BASED ON NEIGHBOR ACCESS POINT LOCATIONS**

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H04W 64/00 (2009.01)

(52) **U.S. Cl.**
CPC ***G01S 5/0247*** (2013.01); ***H04W 64/006*** (2013.01)

(58) **Field of Classification Search**
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USPC 342/357.2, 357.68, 417, 442, 437, 445; 324/207.23, 207.25
See application file for complete search history.

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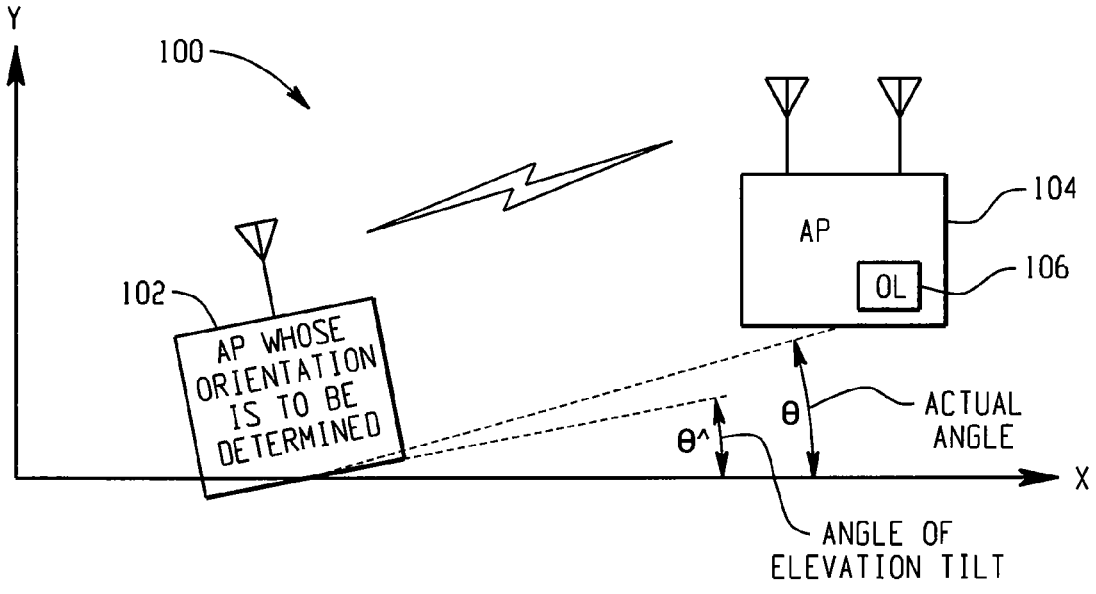
(57) **ABSTRACT**

In an example embodiment, the orientation of a wireless device, such as an access point (AP) can be determined based on the location of neighboring wireless devices and the observed angle of arrival of signals from the wireless device at the neighboring wireless devices. For example, the angle of orientation can be determined by comparing an observed angle of arrival with the known actual angle between wireless devices. If a plurality of wireless devices measure the signal, the mean or median of the difference between observed angle of arrival of a signal from the wireless device with the actual angle for the plurality of wireless devices may be employed to determine the angular orientation.

20 Claims, 4 Drawing Sheets



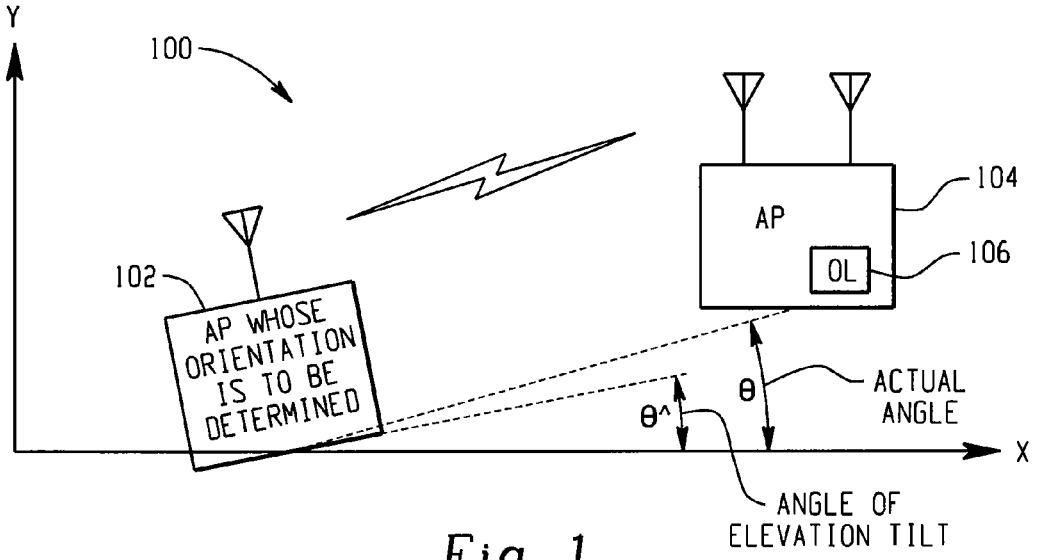

Y
100
104
AP
106
OL
102
AP WHOSE ORIENTATION IS TO BE DETERMINED
θ
ACTUAL ANGLE
θ^
X
ANGLE OF ELEVATION TILT

Fig. 1

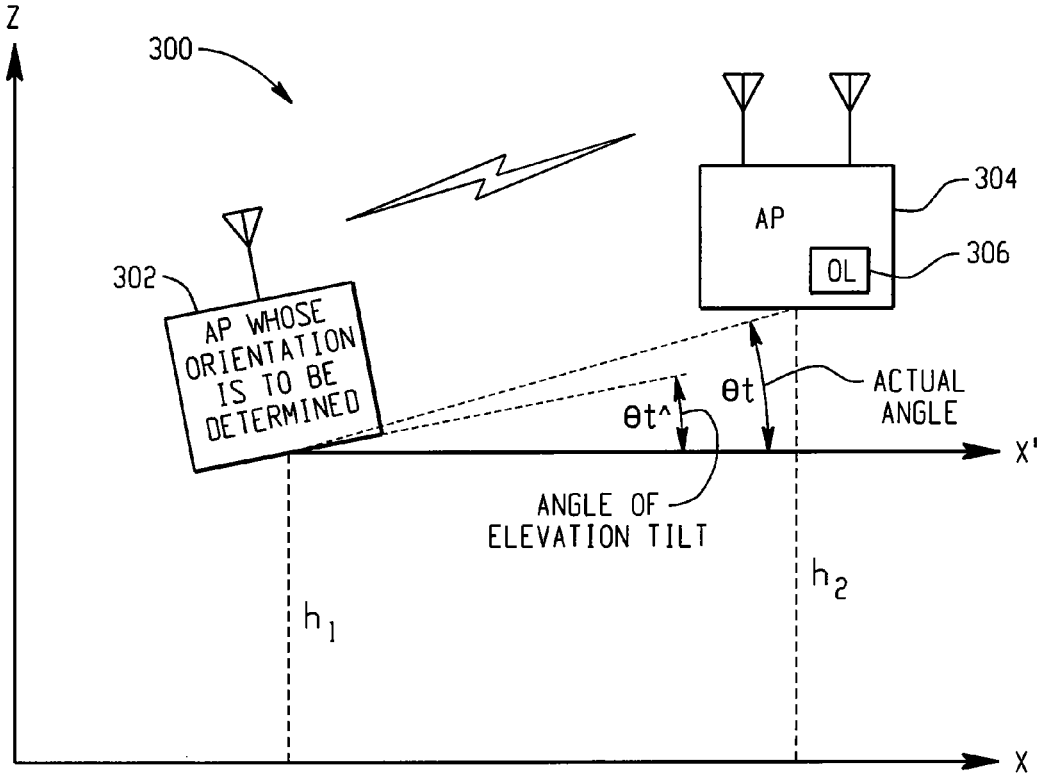

Z
300
304
AP
306
OL
302
AP WHOSE ORIENTATION IS TO BE DETERMINED
θt
ACTUAL ANGLE
θt^
X'
ANGLE OF ELEVATION TILT
h2
h1
X

Fig. 3

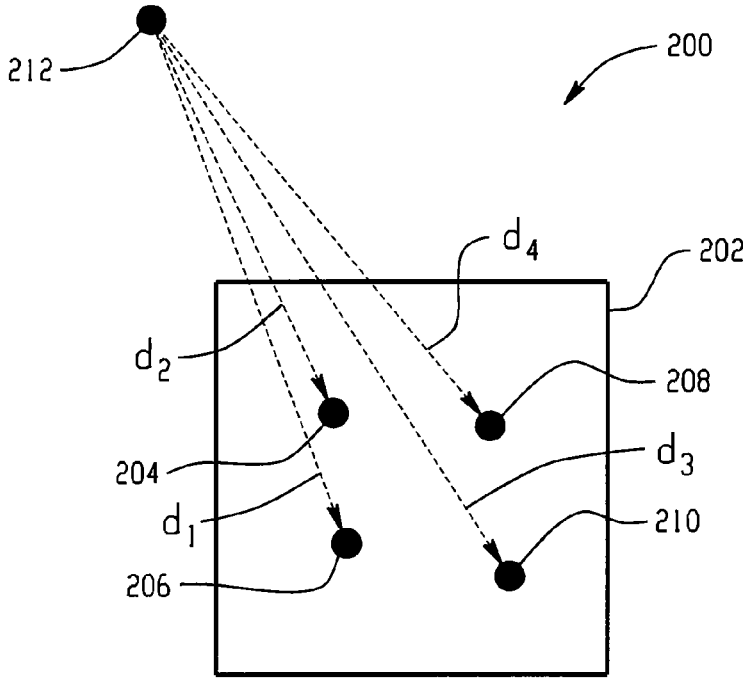

212
200
d_4
202
d_2
208
204
d_3
d_1
210
206

Fig. 2

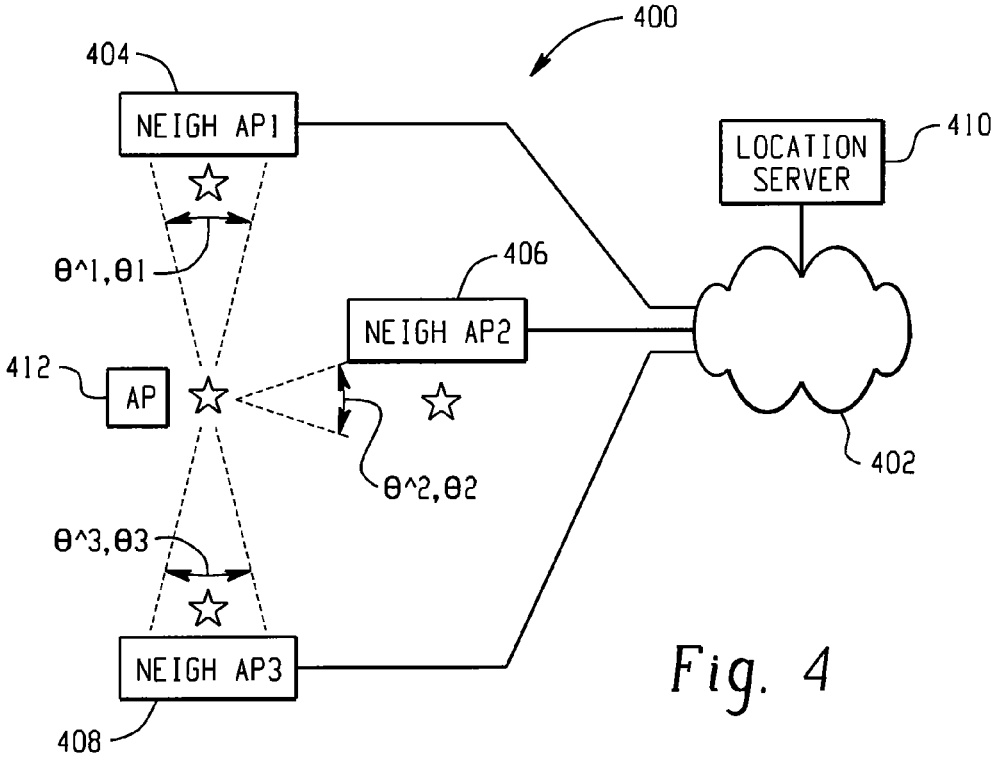

400
404
NEIGH AP1
LOCATION SERVER
410
θ^1,θ1
406
NEIGH AP2
412
AP
θ^2,θ2
402
θ^3,θ3
NEIGH AP3
408

Fig. 4

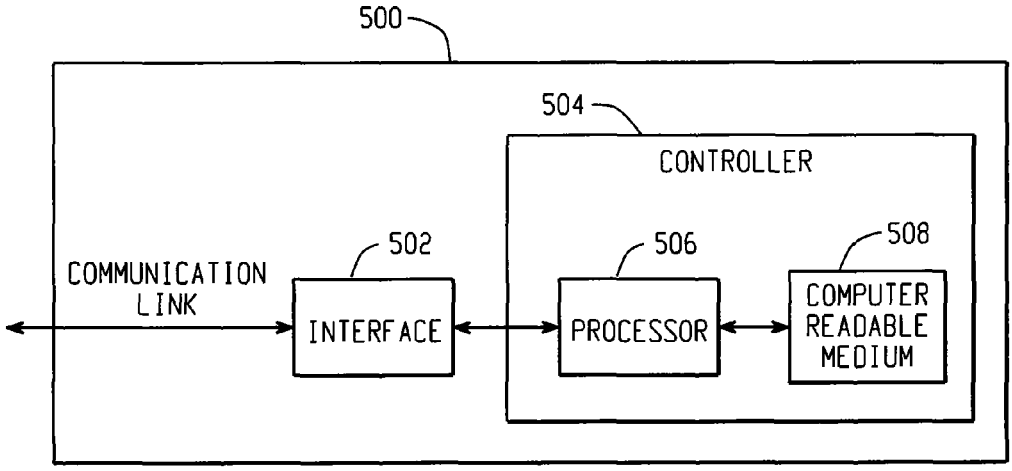

500
504
CONTROLLER
502
506
508
COMMUNICATION LINK
INTERFACE
PROCESSOR
COMPUTER READABLE MEDIUM

Fig. 5

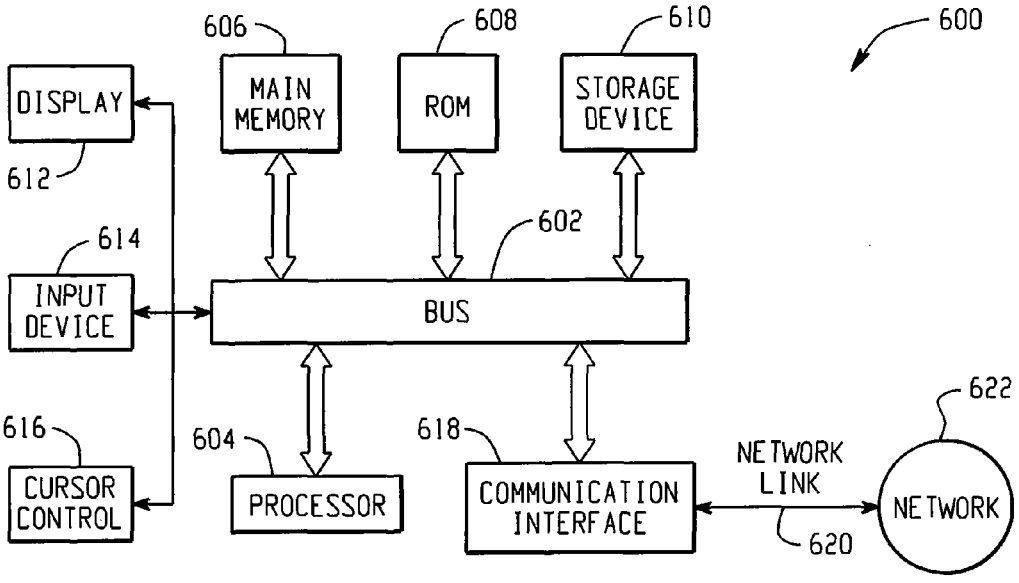

606
608
610
600
DISPLAY
MAIN MEMORY
ROM
STORAGE DEVICE
612
614
602
INPUT DEVICE
BUS
616
604
618
622
CURSOR CONTROL
PROCESSOR
COMMUNICATION INTERFACE
NETWORK LINK
NETWORK
620

Fig. 6

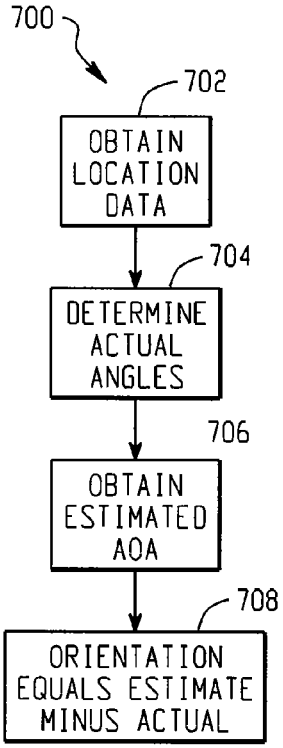


Fig. 7

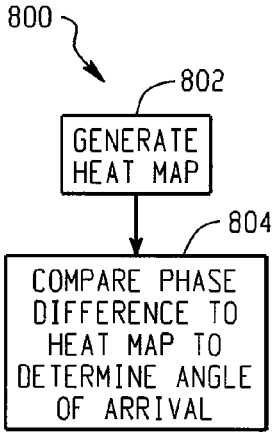


Fig. 8

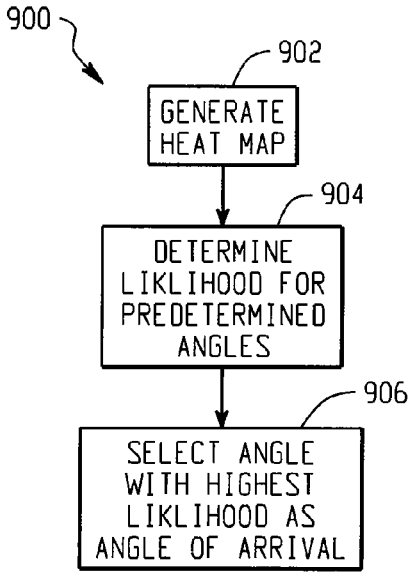


Fig. 9

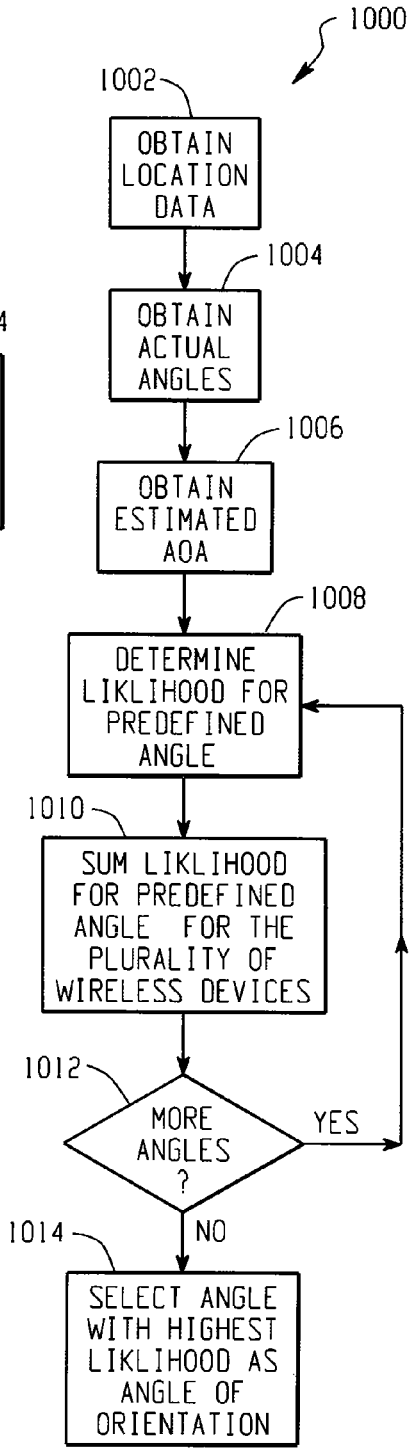


Fig. 10

DETERMINING ACCESS POINT ORIENTATION BASED ON NEIGHBOR ACCESS POINT LOCATIONS

TECHNICAL FIELD

The present disclosure relates generally to wireless devices.

BACKGROUND

Administrators of wireless local area networks desire accurate location and orientation of access points (APs). When a new access point (AP) is added to a network, the installer may manually determine the azimuth and elevation angle of the AP. The azimuth and elevation angle of the AP are employed to determine heatmap estimates, location estimation, network coverage estimation, etc.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram comprising wireless devices for illustrating an example of determining an angle of orientation of a wireless device from an axis.

FIG. **2** illustrates an example of a heat map for determining angle of arrival.

FIG. **3** is a block diagram comprising wireless devices for illustrating an example of determining an elevation tilt angle for a wireless device.

FIG. **4** is a block diagram of an example of a network comprising a plurality of wireless devices for illustrating an example of determining an angle of orientation of a wireless device from an axis based on data obtained from the plurality of wireless devices.

FIG. **5** is a block diagram of an apparatus for determining an angle of orientation and/or elevation tilt angle of a wireless device.

FIG. **6** is block diagram of a computer system upon which an example embodiment can be implemented.

FIG. **7** is an example of a methodology for computing an angle of orientation based on a difference between a measured angle of arrival and an actual angle between wireless devices.

FIG. **8** is an example of a methodology for determining an angle of arrival using a heat map for calculating phase differences between antennas.

FIG. **9** is an example of a methodology for determining an angle of arrival using a heat map and determining a likelihood for a predefined plurality of angles.

FIG. **10** is an example of a methodology for determining an angle of orientation that employs an aggregate likelihood from a plurality of wireless devices.

OVERVIEW OF EXAMPLE EMBODIMENTS

The following presents a simplified overview of the example embodiments in order to provide a basic understanding of some aspects of the example embodiments. This overview is not an extensive overview of the example embodiments. It is intended to neither identify key or critical elements of the example embodiments nor delineate the scope of the appended claims. Its sole purpose is to present some concepts of the example embodiments in a simplified form as a prelude to the more detailed description that is presented later.

In accordance with an example embodiment, there is disclosed herein logic encoded in a tangible, non-transitory computer readable media for execution by a processor. The logic when executed is operable to obtain data representative of locations of a plurality of wireless devices, obtain data representative of angle of arrival of a signal from a wireless device whose orientation is to be determined from wireless devices associated with the plurality of wireless devices, and obtain data representative of an actual angle between the wireless device whose orientation is to be determined and wireless devices associated with the plurality of wireless devices. The logic is operable to determine an orientation of the wireless device whose orientation is to be determined based on a difference of angle of arrival and the actual angle between the wireless device whose orientation is to be determined and wireless devices associated with the plurality of wireless devices.

In accordance with an example embodiment, there is disclosed herein, an apparatus comprising an interface for receiving data; and a controller. The controller comprises orientation logic for determining an orientation of the wireless device whose orientation is to be determined. The controller is operable to obtain data representative of a location of a wireless device. The controller is operable to obtain, via the interface, data representative of angle of arrival of a signal from the wireless device whose orientation is to be determined from the wireless device. The controller is operable to obtain data representative of an actual angle between the wireless device whose orientation is to be determined and the wireless device. The controller is operable to determine an orientation of the wireless device whose orientation is to be determined with respect to a predefined axis based on a difference of angle of arrival and the actual angle between the wireless device whose orientation is to be determined and the wireless device.

In accordance with an example embodiment, there is disclosed herein a method comprising obtaining data representative of a location for a plurality of wireless devices, obtaining data representative of an actual angle between the wireless device whose orientation is to be determined and wireless devices belonging to the plurality of wireless devices, and obtaining data representative of an angle of arrival of a signal from the wireless device whose orientation is to be determined from wireless devices belonging to the plurality of wireless devices. A heat map is generated for a predefined grid around wireless devices belonging to the plurality of wireless devices, the heat maps comprise data representative of phase angles for a signal received from predefined points on the grid for a plurality of antennas associated with the wireless devices belonging to the plurality of wireless devices. The method further comprises determining a likelihood (probability) that a signal came from predefined angles of arrival for the wireless devices belong to the plurality of wireless devices, and determining, by the processor, an aggregate likelihood for predefined angles of orientation. The angle with the highest likelihood is selected as the angle of orientation.

DESCRIPTION OF EXAMPLE EMBODIMENTS

This description provides examples not intended to limit the scope of the appended claims. The figures generally indicate the features of the examples, where it is understood and appreciated that like reference numerals are used to refer to like elements. Reference in the specification to "one embodiment" or "an embodiment" or "an example embodiment" means that a particular feature, structure, or characteristic described is included in at least one embodiment described

herein and does not imply that the feature, structure, or characteristic is present in all embodiments described herein.

FIG. **1** is a block diagram **100** comprising wireless devices (which in this example are APs but the principles described herein can be applied to any suitable wireless devices) **102**, **104** for illustrating an example of determining an angle of orientation (Θˆ), or azimuth, of a wireless device from an axis (in the illustrated example from the X axis although the principles described herein can be employed on any axis or coordinate system). In this example, the locations of APs **102** and **104** are known, the angle of orientation for wireless device **102** is to be determined.

For this example, logic **106** in AP **104** determines the azimuth (Θˆ), however, the logic **106** may physically be located anywhere that is communicatively coupled with AP **104**. "Logic", as used herein, includes but is not limited to hardware, firmware, software and/or combinations of each to perform a function(s) or an action(s), and/or to cause a function or action from another component. For example, based on a desired application or need, logic may include a software controlled microprocessor, discrete logic such as an application specific integrated circuit ("ASIC"), system on a chip ("SoC"), programmable system on a chip ("PSOC"), a programmable/programmed logic device, memory device containing instructions, or the like, or combinational logic embodied in hardware. Logic may also be fully embodied as software stored on a non-transitory, tangible medium which performs a described function when executed by a processor. Logic may suitably comprise one or more modules configured to perform one or more functions.

Because the locations of APs **102** and **104** are known, the actual angle (Θ) between them can be computed. For example, data representative of the locations of APs **102**, **104**, and optionally the actual angle (Θ) may be provided to AP **104** by a location server (not shown) or input via a user interface (not shown). In particular embodiments, the logic **106** in AP **104** computes the actual angle (Θ).

In an example embodiment, AP **104** obtains an angle of arrival (AOA) of a signal sent from AP **102**. The AOA may include an azimuth and/or elevation tilt reading (which will be described in further detail in FIG. **3** herein). The logic **106** determines the orientation (Θˆ) of the wireless device **102** based on a difference of angle of arrival and the actual angle (Θ), (or Θˆ−Θ), between the AP **102** and the AP **104**. In an example embodiment, the elevation of the APs **102** and **104** are assumed to be equal.

In an example embodiment, a heat map may be employed to determine the phase difference of a signal between antennas for computing the angle of arrival. FIG. **2** illustrates an example of a heat map **200** for a wireless device **202** having four antennas **204**, **206**, **208**, **210**. Although the example illustrated in FIG. **2** illustrates four antennas, those skilled in the art should readily appreciate that the principles described herein are applicable to any physically realizable number of antennas.

The heat map **200** comprises a grid with known distances of separation between grid points (which are located at the intersection of the grid lines). For example, a distance of one foot in the X and Y directions may be employed. Although the example illustrated in FIG. **2** is a square grid, those skilled in the art should readily appreciate that any suitable shape (e.g., rectangular) may be employed.

In the illustrated example, a calculation is made for the phase of a signal originating from grid point **212**, where distance d1 is the distance between the grid point **212** and antenna **206**, distance d2 is the distance between the grid point **212** and antenna **204**, d3 is the distance between the grid point **212** and antenna **210**, and d4 is the distance between the grid point **212** and antenna **208**.

The phase (ϕ) in degrees for the antennas **204**, **206**, **208**, **210** from the grid point **212** to an antenna can be calculated as mod(distance, wavelength (λ))/λ*360, where mod is the modulo function. So the phase for antenna **204** is mod(d2, λ)/λ*360; for antenna **206**, mod(d1, λ)/λ*360; for antenna **208**, mod(d4, λ)/λ*360; and for antenna **210**, mod(d3, λ)/λ*360.

Once the phase (ϕ) is computed for the antennas, the phase difference (ϕ_{diff}) can be computed for any pair of antennas. For example, the phase difference (ϕ_{diff}) can be computed for antennas **204** and **206**, antennas **204** and **208**, antennas **204** and **210**, antennas **206** and **208**, antennas **206** and **210**, and antennas **208** and **210**.

In an example embodiment, the orientation logic **106** compares the phase difference of the signal received from a wireless device whose orientation is to be determined with the heat map to determine the angle of arrival of the signal. In particular embodiments, a likelihood (probability) that a signal came from a predefined grid point for the grid points in the heat map is determined and/or a likelihood for predefined angles of rotation about the axis (e.g., one degree intervals) are computed for antenna pairs. The likelihood for the antenna pairs are summed, and the angle with the highest summed likelihood is selected as the angle of arrival.

For example, the likelihood that a phase is from a grid point (e.g., grid point **202**) can be calculated as −log(tt1−tt2), where tt1 is the calculated phase difference from the heat map, and tt2 is the observed phase difference for the antenna pair. Because phase is cyclic, three hundred and sixty degrees should be added to any negative results. The likelihoods for antenna pairs are summed for a grid point to create an aggregate matrix. In particular embodiments, likelihoods may also be aggregated across radial angles of rotation about the axis (e.g., one degree intervals). The angle of arrival is determined to be the angle with the maximum likelihood.

FIG. **3** is a block diagram **300** comprising wireless devices for illustrating an example of determining an elevation tilt angle (Θtˆ) for a wireless device. The actual angle (Θt) between AP **302** and AP **304** is known or can be calculated based on h1 and h2. In an example embodiment, the antennas whose AOA measurements are used for determining the elevation tilt angle (Θtˆ) are at different heights. In the illustrated example embodiment, the elevation tilt angle (Θtˆ) is computed by logic **306** in AP **304**, however, those skilled in the art should readily appreciate that the logic for computing the elevation tilt angle (Θtˆ) can be located anywhere that can obtain the appropriate data.

In an example embodiment, AP **304** obtains an angle of arrival (AOA) of a signal sent from AP **302**. The AOA comprises an elevation tilt reading, but may include an azimuth reading. The logic **306** determines the orientation (Θtˆ) of the AP **302** based on a difference of angle of arrival and the actual angle (Θ), (or Θˆ−Θ), between the AP **302** and the AP **304**. In an example embodiment, the azimuth of APs **302** and **304** are assumed to be equal.

In an example embodiment, a heat map may be employed to determine the phase difference of a signal between antennas for computing the angle of arrival. For example, a heat map similar to the heat map illustrated in FIG. **2** may be constructed for the X-Z plane, and the AOA for the elevation tilt angle may be determined as described in FIG. **2**.

FIG. **4** is a block diagram of an example **400** of a network comprising a plurality of wireless devices **404**, **406**, **408** for illustrating an example of determining an angle of orientation (Θˆ) of a wireless device **412** from an axis based on data

obtained from the plurality of wireless devices **404**, **406**,**408**. In the illustrated example, a location server **410** is employed to calculate the angle of orientation (Θˆ) of wireless device **412**, however, those skilled in the art can readily appreciate the logic for computing the angle of orientation (Θˆ) for the wireless device **412** may be embodied in any suitable infrastructure node, such as, for example, in a wireless switch, wireless LAN (local area network) controller, etc. The location server **410** is communicatively coupled with APs **404**, **406**, **408** via network **402**. Moreover, for ease of illustration, access points (APs) are employed for the illustrated example, however, those skilled in the art should readily appreciate that the principles described herein may be suitably employed by any type of wireless device.

In the illustrated example, the actual angles between AP **404** and AP **412** (Θ1), AP **406** and AP **412** (Θ2), and **408** and AP **412** (Θ3) are known and/or can be calculated based on known locations of APs **404**, **406**, **408**, and **412**. For example, location server **410** can obtain the locations of APs **404**, **406**, **408**, and **412** via a user interface (not shown) and/or can determine their locations based on signals obtained from wireless devices at known locations (e.g., using signal strength, such as, for example, received signal strength indication "RSSI" and/or AOA). The location server **410** obtains data representative of the angle of arrival (Θˆ1) from AP **404**, data representative of the angle of arrival (Θˆ2) from AP **406**, and data representative of the angle of arrival (Θˆ3) from AP **408**. The data representative of angle of arrival received from AP **404**, AP **406**, and AP **408**, Θˆ1, Θˆ2, and Θˆ3 respectively, may suitably comprise data representative of an angle of arrival computed by the AP, and/or data representative of a phase difference measured by the AP's antennas. In an example embodiment, the elevation of APs **404**, **406**, **408**, and **412** are assumed to be equal when computing the azimuth.

In an example embodiment, the azimuth is estimated as the mean of the differences between the measured angles (ΘˆX) actual angles (ΘX). For example the mean of (Θˆ1)−(Θ1), (Θˆ2)−(Θ2), and (Θˆ3)−(Θ3). In another example embodiment, the azimuth is determined by the median of the differences between the measured and computed angles, e.g., median ((Θˆ1)−(Θ1), (Θˆ2)−(Θˆ2), and (Θˆ3)−(Θ3)).

In an example embodiment, the orientation of the wireless device **412** is based on a weighted average of the difference between angle of arrival and actual angle for the plurality of wireless devices. In an example embodiment, a weighted average can be based on the RSSI (Received Signal Strength Indication) of the signals used to calculate the phases. For example if the RSSI used to calculate the phase Θ1 is greater than the one used to calculate the phase Θ2 then the Θˆ1−Θ1 can be given more weight than Θˆ2−Θ2. The weighting factor for an angle Θ_i can be calculated as (rssi_i/sum(RSSI))

In an example embodiment, a heat map is generated for APs **404**, **406**, and **408**. For example, a heat map as described herein for FIG. **2** is generated and employed to determine the angle of arrival Θˆ1, Θˆ2, and Θˆ3 for APs **404**, **406**, and **408** respectively.

In an example embodiment, a probability (likelihood) can be calculated for angles of rotation around the axis (for example, one degree or any desired intervals) for a plurality of wireless devices to determine the azimuth and/or elevation tilt angle. For example, for one degree of rotation, Θˆ1 for one degree of rotation, Θˆ2 for one degree of rotation, and Θˆ3 for one degree of rotation can be computed and compared with Θˆ1, Θˆ2, and Θˆ3 respectively to determine a likelihood (probability) that the AOA measured at by the APs (AP **404**, AP **406**, and AP **408**) corresponds to one degree of rotation. The probabilities for the APs (AP **404**, AP **406**, and AP **408**) can be summed. The computation can be repeated for other desired angles of rotation, and the angle of rotation with the highest sum is selected as the azimuth and/or elevation tilt angle.

FIG. **5** is a block diagram of an apparatus **500** for determining an angle of orientation and/or elevation tilt angle of a wireless device. Apparatus **500** is suitable for implementing the functionality of orientation logic **106** in FIG. **1**, orientation logic **306** in FIG. **3**, and/or location server **410** in FIG. **4**.

In an example embodiment, the apparatus **500** comprises an interface **502** coupled with a communication link. The controller **504** is coupled with the interface **502** and is able to receive data from the communication link via the interface **502**. Controller **504** comprises a processor **506** coupled with a computer readable medium **508**.

An aspect of the example embodiment is related to the use of controller **504** for determination of a wireless device's angular orientation. According to an example embodiment, determining the wireless device's angular orientation is provided by controller **504** in response to processor **506** executing one or more sequences of one or more instructions contained in the computer readable medium **508**. Execution of the instructions contained in the computer readable medium **508** causes processor **506** to perform the functionality described herein. One or more processors in a multi-processing arrangement may also be employed to execute the instructions contained in computer readable medium **508**. In alternative embodiments, hard-wired circuitry may be used in place of or in combination with software instructions to implement an example embodiment. Thus, the example embodiments described herein are not limited to any specific combination of hardware circuitry and software.

The term "computer-readable medium" as used herein refers to any medium that participates in providing instructions to processor **506** for execution. Such a medium may take many forms, including but not limited to non-volatile media, and volatile media. Non-volatile media include for example optical or magnetic disks. Volatile media include dynamic memory, such as a Read Only Memory (ROM) and/or a Random Access Memory ("RAM") which in particular embodiments can be a read/write memory. As used herein, tangible media may include any non-transitory media such as a volatile and non-volatile media. Common forms of computer-readable media include, for example, floppy disk, a flexible disk, hard disk, magnetic cards, paper tape, any other physical medium with patterns of holes, a RAM, a PROM, an EPROM, a FLASHPROM, CD, DVD or any other memory chip or cartridge, or any other medium from which a computer can read.

In an example embodiment, controller **504** is operable to obtain data representative of a location of a wireless device. The controller **504** obtains data representative of angle of arrival of a signal from a wireless device whose orientation is to be determined from the wireless device. The controller **504** also obtains data representative of an actual angle between the wireless device whose orientation is to be determined and the wireless device. The controller **504** determines an orientation (azimuth angle) of the wireless device whose orientation is to be determined based on a difference of angle of arrival and the actual angle between the wireless device whose orientation is to be determined and the wireless device. In an example embodiment, the controller **504** is further operable to determine an elevation tilt angle between the wireless device whose orientation is to be determined and wireless devices associated with the plurality of wireless devices.

In an example embodiment, the controller **504** obtains data representative of location for a plurality of wireless devices.

The data representative of angle of arrival of the signal from the wireless device whose orientation is to be determined is obtained from the plurality of wireless devices, and data representative of an actual angle between the wireless device whose orientation is to be determined and the plurality of wireless devices is obtained. The controller **504** determines the orientation of the wireless device whose orientation is to be determined is based on a difference of angle of arrival and the actual angle for the plurality of wireless devices. In particular embodiments, the orientation of the wireless device whose orientation is to be determined is based on a mean of the difference between angle of arrival and actual angle for the plurality of wireless devices. In other particular embodiments, the orientation of the wireless device whose orientation is to be determined is based on a weighted average of the difference between angle of arrival and actual angle for the plurality of wireless devices. In yet other particular embodiments, the orientation of the wireless device whose orientation is to be determined is based on a median of the difference between angle of arrival and actual angle for the plurality of wireless devices. In an example embodiment, the controller **504** assumes that the elevation of the wireless device whose orientation is to be determined and the plurality of wireless devices are assumed to be equal.

In an example embodiment, the controller **504** generates a heat map for a predefined grid around one or more wireless devices. The heat maps comprise data representative of phase angles for a signal received from predefined points on the grid for a plurality of antennas associated with the wireless devices belonging to the plurality of wireless devices.

In an example embodiment, the controller **504** is operable to compare a phase difference of the signal received from a wireless device whose orientation is to be determined with the heat map to determine the angle of arrival of the signal. In particular embodiments, the controller **504** determines a likelihood that a signal came from a predefined grid point for the grid points in the heat map and selects an angle or arrival corresponding to the grid point with the highest likelihood.

In an example embodiment, the controller **504** determines a likelihood that a signal came from predefined angles of arrival for a plurality of wireless devices. The controller **504** selects an angle of arrival corresponding to the angle with the highest likelihood for wireless devices belonging to the plurality of wireless devices. The controller **504** determines an aggregate likelihood for predefined angles of orientation and selects an angle with the highest aggregated likelihood as the angle of orientation.

FIG. **6** is block diagram of a computer system **600** upon which an example embodiment can be implemented. Computer system **600** may be employed for implementing the functionality of orientation logic **106** described in FIG. **1**, orientation logic **306** described in FIG. **3**, location server **410** described in FIG. **4** and/or controller **504** described in FIG. **5**.

Computer system **600** includes a bus **602** or other communication mechanism for communicating information and a processor **604** coupled with bus **602** for processing information. Computer system **600** also includes a main memory **606**, such as random access memory (RAM) or other dynamic storage device coupled to bus **602** for storing information and instructions to be executed by processor **604**. Main memory **606** also may be used for storing a temporary variable or other intermediate information during execution of instructions to be executed by processor **604**. Computer system **600** further includes a read only memory (ROM) **608** or other static storage device coupled to bus **602** for storing static information and instructions for processor **604**. A storage device **610**, such as a magnetic disk, optical disk, and/or flash storage, is provided and coupled to bus **602** for storing information and instructions.

Computer system **600** may be coupled via bus **602** to a display **612** such as a cathode ray tube (CRT) or liquid crystal display (LCD), and/or Light Emitting Diode (LED) display for displaying information to a computer user. An input device **614**, such as a keyboard including alphanumeric and other keys is coupled to bus **602** for communicating information and command selections to processor **604**. Another type of user input device is cursor control **616**, such as a mouse, a trackball, cursor direction keys, and/or a touchscreen for communicating direction information and command selections to processor **604** and for controlling cursor movement on display **612**. This input device typically has two degrees of freedom in two axes, a first axis (e.g., x) and a second axis (e.g., y) that allows the device to specify positions in a plane. Input device **614** may be employed for obtaining data representative of a location of known wireless devices, and optionally the actual angle between the known wireless devices and a wireless device whose angular orientation is to be determined.

An aspect of the example embodiment is related to the use of computer system **600** for determining angular orientation of a wireless device. According to an example embodiment, determining angular orientation is provided by computer system **600** in response to processor **604** executing one or more sequences of one or more instructions contained in main memory **606**. Such instructions may be read into main memory **606** from another computer-readable medium, such as storage device **610**. Execution of the sequence of instructions contained in main memory **606** causes processor **604** to perform the process steps described herein. One or more processors in a multi-processing arrangement may also be employed to execute the sequences of instructions contained in main memory **606**. In alternative embodiments, hard-wired circuitry may be used in place of or in combination with software instructions to implement an example embodiment. Thus, embodiments described herein are not limited to any specific combination of hardware circuitry and software.

Computer system **600** also includes a communication interface **618** coupled to bus **602**. Communication interface **618** provides a two-way data communication coupling computer system **600** to a communication (in this example a network) link **620** that is connected to a local network **622**. For example, communication interface **618** may be a local area network (LAN) card to provide a data communication connection to a compatible LAN. As another example, communication interface **618** may be an integrated services digital network (ISDN) card or a modem to provide a data communication connection to a corresponding type of telephone line. Wireless links may also be implemented. In any such implementation, communication interface **618** sends and receives electrical, electromagnetic, or optical signals that carry digital data streams representing various types of information.

In view of the foregoing structural and functional features described above, methodologies in accordance with an example embodiments will be better appreciated with reference to FIGS. **7-10**. While, for purposes of simplicity of explanation, the methodologies of FIGS. **7-10** are shown and described as executing serially, it is to be understood and appreciated that the example embodiments are not limited by the illustrated orders, as some aspects could occur in different orders and/or concurrently with other aspects from that shown and described herein. Moreover, not all illustrated features may be required to implement the methodologies.

The methodologies described herein are suitably adapted to be implemented in hardware, software, or a combination thereof.

FIG. **7** is an example of a methodology **700** for computing an angle of orientation based on a difference between a measured angle of arrival and an actual angle between wireless devices. Methodology **700** may be implemented by AP **104** (FIG. **1**), AP **304** (FIG. **3**), location server **410** (FIG. **4**), controller **504** (FIG. **5**) and/or computer system **600** (FIG. **6**).

At **702**, data representative of the location data for wireless devices is obtained. The location data may be obtained via a user interface. For some devices, the location may be calculated based on the signal strength (e.g., "RSSI") and/or AOA of signals received by devices at known locations.

At **704**, data representative of the actual angles between known wireless devices and the wireless device whose angular rotation is to be determined is obtained. In an example embodiment, the angles may be obtained via a user interface. In another example embodiment, the actual angles are received from another device, such as, for example, a location server. In yet another example embodiment, the actual angle is determined based on the location of the device whose angular orientation is to be determined and the known locations of the device or devices receiving a signal from the device whose angular orientation is to be determined.

At **706**, data representative of an angle of arrival (AOA) is obtained. The AOA may include an azimuth and/or elevation tilt reading.

In an example embodiment, a heat map may be employed to determine the phase difference of a signal between antennas for computing the angle of arrival. For example FIG. **2** illustrates an example of a heat map **200**.

The heat map **200** comprises a grid with known distances of separation between grid points (which are located at the intersection of the grid lines). For example, a distance of one foot in the X and Y directions may be employed. Although the example illustrated in FIG. **2** is a square grid, those skilled in the art should readily appreciate that any suitable shape (e.g., rectangular) may be employed.

A phase is computed from a reference point for a plurality of antennas associated with the device receiving a signal from the device whose orientation is to be determined. Once the phase (ϕ) is computed for the antennas, the phase difference (ϕ_{diff}) can be computed for any pair of antennas. For example, in FIG. **2** the phase difference (ϕ_{diff}) can be computed for antennas **204** and **206**, antennas **204** and **208**, antennas **204** and **210**, antennas **206** and **208**, antennas **206** and **210**, and antennas **208** and **210**. As described herein, the phase difference of the signal received from the wireless device whose orientation is to be determined is compared with the phase differences calculated from the heat map to determine an angle of arrival. In particular embodiments, the probability (likelihood) for various angles of arrival are computed and the angle of arrival with the highest probability is selected as the angle of arrival.

At **708**, the orientation (azimuth and/or elevation tilt) angle is computed. In an example embodiment, the azimuth is estimated as the mean of the differences between the measured angles ($\Theta\hat{}$) actual angles (ΘX). For example, for measurements received from three devices, the angle of orientation would be the mean of ($\Theta\hat{}1$)−($\Theta 1$), ($\Theta\hat{}2$)−($\Theta 2$), and ($\Theta\hat{}3$)−($\Theta 3$). In another example embodiment, the azimuth is determined by the median of the differences between the measured and computed angles, e.g., median (($\Theta\hat{}1$)−($\Theta 1$), ($\Theta\hat{}2$)−($\Theta 2$), and ($\Theta\hat{}3$)−($\Theta 3$)). In yet another example embodiment, a probability (likelihood) can be calculated for angles of rotation around the axis (for example, one degree or any desired intervals) for a plurality of wireless devices to determine the azimuth and/or elevation tilt angle. The probabilities for an angle of rotation can be aggregated (summed), and the angle with the highest aggregated probability is selected as the angle of orientation.

FIG. **8** is an example of a methodology **800** for determining an angle of arrival using a heat map for calculating phase differences between antennas. Methodology **800** may be implemented by AP **104** (FIG. **1**), AP **304** (FIG. **3**), location server **410** (FIG. **4**), controller **504** (FIG. **5**) and/or computer system **600** (FIG. **6**).

At **802**, a heat map is generated. The heat map comprises a grid with known distances of separation between grid points (which are located at the intersection of the grid lines). For example, a distance of one foot in the X and Y directions may be employed. Any suitable shape (e.g., square, rectangular, etc.) may be employed for the heat map.

A calculation is made for the phase of a signal originating from grid points on the heat map and antennas associated with the wireless device that received the signal from the device whose angular orientation is to be determined. The phase (ϕ) in degrees for an antennas from the grid point to an antenna can be calculated as mod(distance, wavelength (λ))/λ*360, where mod is the modulo function. Once the phase (ϕ) is computed for the antennas, the phase difference (ϕ_{diff}) can be computed for any pair of antennas.

At **804**, the phase difference of the signal received from a wireless device whose orientation is to be determined is compared with calculated phase differences from the heat map to determine the angle of arrival of the signal. The best match is selected as the angle of arrival. As will be described herein in FIG. **9**, a probability function may be employed to select the angle of arrival.

FIG. **9** is an example of a methodology **900** for determining an angle of arrival using a heat map and determining a likelihood for a predefined plurality of angles. Methodology **900** may be implemented by AP **104** (FIG. **1**), AP **304** (FIG. **3**), location server **410** (FIG. **4**), controller **504** (FIG. **5**) and/or computer system **600** (FIG. **6**).

At **902**, a heat map is generated. The heat map comprises a grid with known distances of separation between grid points (which are located at the intersection of the grid lines). For example, a distance of one foot in the X and Y directions may be employed. Any suitable shape (e.g., square, rectangular, etc.) may be employed for the heat map.

A calculation is made for the phase of a signal originating from grid points on the heat map and antennas associated with the wireless device that received the signal from the device whose angular orientation is to be determined. The phase (ϕ) in degrees for an antennas from the grid point to an antenna can be calculated as mod(distance, wavelength (λ))/λ*360, where mod is the modulo function. Once the phase (ϕ) is computed for the antennas, the phase difference (ϕ_{diff}) can be computed for any pair of antennas.

At **904**, a likelihood (probability) that a signal came from a predefined grid point for the grid points in the heat is determined and/or a likelihood for predefined angles of rotation about the axis (e.g., one degree intervals) are computed for antenna pairs. The likelihood for the antenna pairs are summed, and the angle with the highest summed likelihood is selected as the angle of arrival.

For example, the likelihood that a phase is from a grid point (e.g., grid point **202**) can be calculated as −log(tt1−tt2), where tt1 is the calculated phase difference from the heat map, and tt2 is the observed phase difference for the antenna pair. Because phase is cyclic, three hundred and sixty degrees should be added to any negative results. The likelihoods for

antenna pairs are summed for a grid point to create an aggregate matrix. In particular embodiments, likelihoods may also be aggregated across radial angles of rotation about the axis (e.g., one degree intervals).

At **906**, the angle of arrival is selected. In an example embodiment, the angle of arrival is determined to be the angle with the maximum likelihood.

FIG. **10** is an example of a methodology **1000** for determining an angle of orientation that employs an aggregate likelihood from a plurality of wireless devices. Methodology **1000** may be implemented by AP **104** (FIG. **1**), AP **304** (FIG. **3**), location server **410** (FIG. **4**), controller **504** (FIG. **5**) and/or computer system **600** (FIG. **6**).

At **1002**, data representative of the location data for wireless devices is obtained. The location data may be obtained via a user interface. For some devices, the location may be calculated based on the signal strength (e.g., "RSSI") and/or AOA of signals received by devices at known locations.

At **1004**, data representative of the actual angles between known wireless devices and the wireless device whose angular rotation is to be determined is obtained. In an example embodiment, the angles may be obtained via a user interface. In another example embodiment, the actual angles are received from another device, such as, for example, a location server. In yet another example embodiment, the actual angle is determined based on the location of the device whose angular orientation is to be determined and the known locations of the device or devices receiving a signal from the device whose angular orientation is to be determined.

At **1006**, data representative of an angle of arrival (AOA) is obtained. The AOA may include an azimuth and/or elevation tilt reading.

In an example embodiment, a heat map may be employed to determine the phase difference of a signal between antennas for computing the angle of arrival. For example FIG. **2** illustrates an example of a heat map **200**.

The heat map **200** comprises a grid with known distances of separation between grid points (which are located at the intersection of the grid lines). For example, a distance of one foot in the X and Y directions may be employed. Although the example illustrated in FIG. **2** is a square grid, those skilled in the art should readily appreciate that any suitable shape (e.g., rectangular) may be employed.

A phase is computed from a reference point for a plurality of antennas associated with the device receiving a signal from the device whose orientation is to be determined. Once the phase (ϕ) is computed for the antennas, the phase difference (ϕ_{diff}) can be computed for any pair of antennas. For example, in FIG. **2** the phase difference (ϕ_{diff}) can be computed for antennas **204** and **206**, antennas **204** and **208**, antennas **204** and **210**, antennas **206** and **208**, antennas **206** and **210**, and antennas **208** and **210**. As described herein, the phase difference of the signal received from the wireless device whose orientation is to be determined is compared with the phase differences calculated from the heat map to determine an angle of arrival. In particular embodiments, the probability (likelihood) for various angles of arrival are computed and the angle of arrival with the highest probability is selected as the angle of arrival.

At **1008**, the likelihood that a signal from the wireless device whose orientation is to be determined is calculated for a predetermined angular displacement (rotation). A likelihood (probability) is calculated for a plurality of wireless devices that received a signal from the wireless device whose orientation is to be determined. At **1010**, the likelihood (probability) for the plurality of devices receiving the signal are summed.

At **1012**, a determination is made whether calculations should be performed for additional angular displacements. If there are additional angular rotations to be calculated (YES), **1010** is repeated for the next angular rotation. If there are no more angular rotations to be calculated (NO), at **1014**, the angular rotation (angle) with the highest likelihood (summed likelihoods from the plurality of wireless devices receiving the signal from the wireless device whose angular rotation is to be determined is selected.

Described above are example embodiments. It is, of course, not possible to describe every conceivable combination of components or methodologies, but one of ordinary skill in the art will recognize that many further combinations and permutations of the example embodiments are possible. Accordingly, this application is intended to embrace all such alterations, modifications and variations that fall within the spirit and scope of the appended claims interpreted in accordance with the breadth to which they are fairly, legally and equitably entitled.

The invention claimed is:

1. Logic encoded in a tangible, non-transitory computer readable media for execution by a processor, and when executed, the logic is operable to:

obtain data representative of a location of a wireless device;

obtain data representative of an angle of arrival of a signal from a wireless device whose orientation is to be determined from the wireless device;

obtain data representative of an actual angle between the wireless device whose orientation is to be determined and the wireless device; and

determine an orientation of the wireless device whose orientation is to be determined based on a difference of the angle of arrival and the actual angle between the wireless device whose orientation is to be determined and the wireless device.

2. The logic set forth in claim **1**, wherein data representative of respective locations for a plurality of wireless devices is obtained;

wherein data representative of a plurality of angles of arrival of the signal from the wireless device whose orientation is to be determined is obtained from the plurality of wireless devices;

wherein data representative of respective actual angles between the wireless device whose orientation is to be determined and the plurality of wireless devices is obtained; and

wherein the orientation of the wireless device whose orientation is to be determined is based on a difference of the angles of arrival and the actual angles for the plurality of wireless devices.

3. The logic set forth in claim **2**, wherein the orientation of the wireless device whose orientation is to be determined is based on a mean of the difference between the angles of arrival and the actual angles for the plurality of wireless devices.

4. The logic set forth in claim **2**, wherein the orientation of the wireless device whose orientation is to be determined is based on a weighted average of the difference between the angles of arrival and the actual angles for the plurality of wireless devices.

5. The logic set forth in claim **2**, wherein the orientation of the wireless device whose orientation is to be determined is based on a median of the difference between the angles of arrival and the actual angles for the plurality of wireless devices.

6. The logic set forth in claim 2, wherein the elevation of the wireless device whose orientation is to be determined and the plurality of wireless devices are assumed to be equal.

7. The logic set forth in claim 2, further operable to:

generate a heat map for a predefined grid around wireless devices belonging to the plurality of wireless devices, the heat map comprises data representative of phase angles for a signal received from predefined points on the grid for a plurality of antennas associated with the wireless devices belonging to the plurality of wireless devices;

determine a likelihood that a signal came from predefined angles of arrival for the wireless devices belonging to the plurality of wireless devices;

select a first angle corresponding to an angle with the highest likelihood for wireless devices belonging to the plurality of wireless devices;

determine an aggregated likelihood for predefined angles of orientation; and

select an angle with the highest aggregated likelihood.

8. The logic set forth in claim 1, further operable to determine an elevation tilt angle between the wireless device whose orientation is to be determined and wireless devices associated with the plurality of wireless devices.

9. The logic set forth in claim 1, further operable to:

generate a heat map for a predefined grid around the wireless device, the heat map comprises data representative of phase angles for a signal received from points on the grid for a plurality of antennas associated with the wireless device; and

compare a phase difference of the signal received from a wireless device whose orientation is to be determined with the heat map to determine the angle of arrival of the signal.

10. The logic set forth in claim 1, further operable to:

generate a heat map for a predefined grid around the wireless device, the heat map comprises data representative of phase angles for a signal received from points on the grid for a plurality of antennas associated with the wireless device;

determine a likelihood that a signal came from a predefined grid point for the grid points in the heat map; and

select an angle corresponding to the grid point with the highest likelihood as the angle of arrival.

11. An apparatus, comprising:

an interface for receiving data; and

a controller, the controller comprises orientation logic for determining an orientation of the wireless device whose orientation is to be determined;

the controller is operable to obtain data representative of a location of a wireless device;

the controller is operable to obtain via the interface, data representative of an angle of arrival of a signal from the wireless device whose orientation is to be determined from the wireless device;

the controller is operable to obtain data representative of an actual angle between the wireless device whose orientation is to be determined and the wireless device; and

the controller is operable to determine an orientation of the wireless device whose orientation is to be determined with respect to a predefined axis based on a difference of the angle of arrival and the actual angle between the wireless device whose orientation is to be determined and the wireless device.

12. The apparatus set forth in claim 11, wherein data representative of respective locations for a plurality of wireless devices is obtained;

wherein data representative of a plurality of angles of arrival of the signal from the wireless device whose orientation is to be determined is obtained from the plurality of wireless devices;

wherein data representative of respective actual angles between the wireless device whose orientation is to be determined and the plurality of wireless devices is obtained; and

the controller is further operable to determine the orientation of the wireless device whose orientation is to be determined is based on a difference of the angles of arrival and the actual angles for the plurality of wireless devices.

13. The apparatus set forth in claim 12, the controller is further operable to generate a heat map for a predefined grid around wireless devices belonging to the plurality of wireless device, the heat map comprises data representative of phase angles for a signal received from predefined points on the grid for a plurality of antennas associated with the wireless devices belonging to the plurality of wireless devices;

the controller is operable to determine a likelihood that a signal came from predefined angles of arrival for the wireless devices belonging to the plurality of wireless devices;

the controller is operable to select an angle corresponding with the highest likelihood for wireless devices belonging to the plurality of wireless devices as the angle of arrival;

the controller is operable to determine an aggregate likelihood for predefined angles of orientation; and

the controller is operable to select an angle with the highest likelihood.

14. The apparatus set forth in claim 11, the controller is further operable to determine an elevation tilt angle between the wireless device whose orientation is to be determined and wireless devices associated with the plurality of wireless devices.

15. The apparatus set forth in claim 11, the controller is further operable to generate a heat map for a predefined grid around the wireless device, the heat map comprises data representative of phase angles for a signal received from points on the grid for a plurality of antennas associated with the wireless device; and

the controller is operable to compare a phase difference from the signal received from a wireless device whose orientation is to be determined with the heat map to determine the angle of arrival of the signal.

16. The apparatus set forth in claim 11, the controller is further operable to generate a heat map for a predefined grid around the wireless device, the heat map comprises data representative of phase angles for a signal received from points on the grid for a plurality of antennas associated with the wireless device;

the controller is operable to determine a likelihood that a signal came from a predefined grid point for the grid points in the heat map; and

the controller is operable to select the angle of arrival corresponding to the grid point with the highest likelihood.

17. A method, comprising:

obtaining data representative of respective locations for a plurality of wireless devices;

obtaining data representative of respective actual angles between a wireless device whose orientation is to be determined and wireless devices belonging to the plurality of wireless devices;

obtaining data representative of an angle of arrival of a signal from the wireless device whose orientation is to be determined from wireless devices belonging to the plurality of wireless devices; and

generating a heat map for a predefined grid around wireless devices belonging to the plurality of wireless device, the heat map comprises data representative of phase angles for a signal received from predefined points on the grid for a plurality of antennas associated with the wireless devices belonging to the plurality of wireless devices;

determining a likelihood that a signal came from predefined angles of arrival for the wireless devices belonging to the plurality of wireless devices;

determining, by a processor, an aggregate likelihood for predefined angles of orientation; and

selecting, by the processor, an angle with the highest likelihood as the angle of orientation.

18. The method set forth in claim **17**, further comprising:

determining for a wireless device belonging to the plurality of wireless devices, a plurality of phase differences corresponding to a plurality of antenna pairs; and

wherein determining a likelihood that the signal came from predefined angles further comprises comparing, by the processor, the plurality of phase differences from the signal received from the wireless device whose orientation is to be determined with a plurality of phase differences in the heat map.

19. The method set forth in claim **17**, wherein the predefined angles are one degree increments about the axis.

20. The method set forth in claim **17**, wherein determining an aggregate comprises summing the likelihood for wireless devices belonging to the plurality of wireless devices for a predefined angle.

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